Causal, psychological, and electrodynamic time arrows as consequences of the thermodynamic time arrow

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Abstract

A clear explanation is given on how the causal, psychological, and electrodynamic time arrows emerge from the thermodynamic time arrow.

Most of physicists agree that the causal, psychological, and electrodynamic time-arrows are consequences of the thermodynamic time-arrow. For example, such a viewpoint is explicitly expressed in famous books [1], [2] (see also [3] for some other references). However, it is our feeling that the existing literature does not explain the relations among various manifestations of the time arrow in a sufficiently clear way, and that there is still a lot of misunderstanding among some physicists about the true origin of the time arrow. We believe that we are able to clear up how the causal, psychological, and electrodynamic time arrow emerge from the classical, deterministic physical laws and the assumption that disorder increases with time.

Let us start with the causality principle. By causality we understand a "fact" that "causes" happen before "consequences". Such a claim does not make any sense at the fundamental level because the state of a physical system at any instant t can be viewed as a "cause" of states for all other instants, larger or smaller than t, in the sense that it uniquely determines these states via the equations of motion. However, it does make sense at some effective, macroscopic level. This is connected with the fact that, in practice, we try to draw conclusions about the future and about the past without knowing *details* of the present state. Thus, our conclusions are to a great extent based on statistical arguments. And since disorder increases with time, statistical arguments can determine the past much better than the future. Thus it is easy to see a connection between the presence and the past, but it is not so easy to see a connection between the presence and the future. That

is why we can consider the past as a "cause" of the presence, whereas can not consider the future as a "cause" of the presence.

This can also explain the psychological time-arrow. Our psychological feeling that the time lapses is a consequence of the fact that we remember, i.e., our brain possesses the information about the events that do not refere to the present time. The problem of the origin of the psychological time-arrow is reduced to the question why we remember the past, but not the future.

The general mechanism of memorizing is the following: Some event in the past causes some permanent consequence. Recalling is just observation of this consequence at an arbitrary later instant. In other words, by observing the present state of a system, we may draw the conclusion about its past, i.e., about the event that caused the present permanent consequence. As we have already discussed, we cannot so easily draw conclusions about its future, except that the permanent consequence will keep its form yet for some time, which is not the information about any *event* in the future.

Let us now discuss the status of causality in classical electrodynamics (similar arguments can also be applied to all other classical field theories). We consider a system which consists of charged currents and electromagnetic fields, both being time dependent. We usually assume that the vector potential $A^{\mu}(x)$ is given by the retarded solution of the equation

$$\Box A^{\mu}(x) = J^{\mu}(x) \ . \tag{1}$$

It is usually argued that we have to take the retarded solution because of the causality principle, i.e., because the cause (moving charges) must precede the consequence (electromagnetic fields). However, the essential tacit assumption is that the charges *are* the cause and that the electromagnetic fields *are* the consequence. Such a viewpoint is partly influenced by equation (1), where it is tacitly assumed that $J^{\mu}(x)$ is some known function, whereas $A^{\mu}(x)$ is a function to be determined from (1). However, this is only an idealization. Electrodynamics is actually a system of equations, one of which is (1), whereas the other is the differential equation for charged "matter" fields, interacting with electromagnetic fields. This system should actually be solved self-consistently, so there is no separation of fields into "causes" and "consequences" at the fundamental level. The electromagnetic field is the cause of motion of the charge equally as the motion of the charge is the cause of the electromagnetic field.

Furthermore, advanced solutions are not unphysical at all. For example, it is possible to construct a large spherical source of electromagnetic waves which emits waves from the sphere to the inner area. When these waves come to the center, they force the positive and negative charges in the center to oscillate. In the inner area of the sphere this looks just as the advanced solution of (1).

However, there is one peculiarity with this picture. One could argue that this would be inconsistent if positive and negative charges were not present in the center at the beginning. However, it is clear that there is no incosistency from the point of view of quantum electrodynamics; the strong fields in the center can create electron-positron pairs. This is also consistent with the classical *field* theory of charged matter, because nothing prevents induction of local charge densities as long as the total charge is conserved.

Although the advanced solutions are not unphysical, it is still true that the retarded solution is the appropriate one for most of practical purposes. This is because in practice

it is rather difficult to prepare such initial conditions (such as a large spherical source) that would correspond to the advanced solution in a large volume V. This can also be explained by the principle of disorder increase; in a typical physical situation, the energy is first concentrated inside the small lumps of matter (small disorder) and then dissipated all around via electromagnetic waves (large disorder).

Finally, let us stress that the fact that disorder is growing with time is equivalent to the statement that the Universe was quite ordered in the past. Thus, the only real problem with the time arrow is to explain *why* the Universe was so ordered at some instant of time of its evolution. There is still no convincing explanation of this, except the anthropic principle [4].

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References

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